3|RR75
10/535118
JC13 Rec'd PCT/PTO 16 MAY 2005



# METHOD FOR DEPICTING AN OBJECT DISPLAYED IN A VOLUME DATA SET

The invention concerns a method for representation of a subject represented in a volume data set.

Images acquired with modern imaging medicine-related apparatuses in particular exhibit a relatively high resolution, such that enhanced 3D exposures (volume data sets) can be generated with them. Imaging medicine-related apparatuses are, for example, ultrasound, computer tomography, magnetic resonance or x-ray apparatuses or PET scanners. Furthermore, computer tomography (CT) or x-ray apparatuses can be used more often since a radiation exposure that an organism is exposed to during an examination with one of these apparatuses has decreased. However, volume data sets contain a larger data quantity than image data sets of conventional two-dimensional images, which is why an evaluation of volume data sets is relatively time-consuming. The actual acquisition of the volume data sets lasts approximately half a minute, in contrast to which a half-hour or more is often needed to thin out and prepare the volume data set. Automatic detection and preparation methods are therefore necessary and welcome.

Until approximately the year 2000, it was typical nearly only in computer tomography (CT) to make a diagnosis using axial slice stacks (slice images) or to at least orient oneself predominantly on the slice images for a finding. Thanks to the computing capacity of computers, 3D representations have expanded to finding consoles since approximately 1995; however, they initially had a more scientific or supplementary importance. In order to make a diagnosis easier for a doctor, four basic methods of 3D visualization have also been developed:

1. Multiplanar reformatting (MPR): This is nothing other than a reconfiguration if the volume data set in a different orientation than, for example,

the original horizontal slices. In particular, differentiation is made between orthogonal MPR (3 MPRs, respectively perpendicular to one of the original coordinate axes), free MPR (angled slices; derived = interpolated) and curved MPR (slice generation parallel to an arbitrary path through the image of the body of the organism and, for example, perpendicular to the MPR in which the path was plotted).

2. Shaded surface display (SSD): Segmenting of the volume data set and representation of the surface of the excised objects, most strongly characterized by orientation to the grey values of the image (for example CT values) and manual auxiliary editing.

3. Maximal intensity projection (MIP): Representation of the highest intensity along each ray. Only a partial volume is represented in what is known as Thin MIP.

4. Volume rendering (VR): What is understood by this is a modeling using rays that penetrate into the subject or exit from the subject comparable to x-rays. The entire depth of the imaged body (partially translucent) is thereby acquired; however, details of small objects and especially objects shown in a thin layer are lost. The representation is manually characterized by adjustment of what are known as transfer functions (color lookup tables). Illumination effects can be to be mixed in, in that further storage planes are used in which gradient contribution and direction for the illumination are stored and allowed for in the representation.

However, a disadvantage of the known methods is the insufficient representation of relatively fine structures, in particular when a relatively large volume data set is present. A further disadvantage of the known method is that respectively only the entire 3D block is shown in a fixed context.

It is therefore the object of the invention to specify a method with which relatively fine structures, in particular structures imaged in a relatively large volume data set, are shown in an improved manner.

The object of the invention is achieved by a method for representation of a subject imaged in a first volume data set, which method comprises the following method steps:

- generation of a second volume data set in which the volume elements of the first volume data set are modulated and/or coded, dependent on depth, parallel to the main observation direction running in the first volume data set, and

- application of volume rendering on the second volume data set.

It is the goal and the object of the inventive method to achieve a continuous 3D representation through the entire depth of the imaged subject via a further development of the volume rendering, without a special segmentation of the subject imaged in the first volume data set. The first volume data set is, for example, generated with a computer tomograph or a magnetic resonance apparatus, in general with an imaging apparatus that is suitable for generation of a volume data set.

Additionally, a spatial and plastic impression of the imaged subject is inventively, simultaneously achieved via a depth shading. For this, the second volume data set is inventively produced from the first volume data set, in that preferably all volume elements (in CT for example in Hounsfield units) of the first volume data set are depth-dependently modulated or, respectively, coded and stored in the direction of the main observation direction, and the known volume rendering is applied to the second volume data set. Volume rendering is, for example, described in Foley et

al., "Computer Graphics: Principle and Practice [sic], 2nd edition, Addison-Wesley, 1990, pages 1034 through 1039. For example, on the one hand in the sense of a depth shading the plastic 3D impression is thus improved in cooperation with what is known as alpha blending.

The alpha value determines the transparency or, respectively, opacity of the represented subjects and is defined for each possible value of the volume data. On the other hand, a continuous selection possibility results for the respectively shown depth range. This is non-trivial since, for example, a broad spectrum of measurement values exists in computer tomography. The imaged subject is, for example, a body of an organism. A specific density of contrast agent or bone (spinal column) further back in the imaged body of the organism with a strong opaquely-set alpha is always x-rayed towards the front with regard to a viewing direction (ray) of an observer when occluding objects along the ray extend only to a limited extent and exhibit an alpha that is set less opaque (= transparent). This contradiction cannot be resolved with conventional volume rendering. In an occlusion line (along the ray), only one subject can ever actually be shown completely clearly and a switch over to the representation of other subjects entails effort and significant modification of the image impression.

Via depth selection, in particular in real time, the inventive method now offers the possibility to represent all partial subjects (organs) without change of the overall impression, with complete contrast and depth shading. So to speak, a further alpha is impressed on the volume data set in the main observation direction with a different inertia than the exponential decay of the alpha blending and adjusted to the preservation of the density modulation in the first volume data set (in CT, for example in Hounsfield units). This is applied such that a depth shading (thus a shadow formation at the edges from the front to the back) results locally on the imaged partial subjects, whereby all partial subjects appear plastic.

For example, with a sliding control it can be continuously adjusted which depth range should be shown, whereby the sliding control acts on a sub-range of the transfer function that is shifted on the value scale of the modulated or, respectively, coded volume data set. It is thereby novel that the updating of the representation can in particular ensue in real time because the volume data are already stored beforehand in the suitable modulation or, respectively, coding, for example in a display storage, for example of a conventional graphic card. This adjustment is also comparable with the adjustment of the depth of field in photography. However, in contrast to the photographic depth of field, here the possibility exists to define the front and rear edge significantly more precisely, for example with a rectangular transfer function, which is primarily important to the observer in order to completely fade out viewing obstacles.

The corresponding design of the transfer function, in the simplest case (for example) ramp functions falling off to the rear with regard to the observer when a depth shading from the front to the back is desired or (as it is provided according to an embodiment of the invention) in the form of a modified rectangle or bar whose canted upper edge falls off to the rear, involves the coded or, respectively, modulated storage of the volume in the form of the second volume data set in the storage. According to a variant of the inventive method, the transfer function is stored in a lookup table. Instead of a slide control, a mouse- [sic] or other controller, the depth adjustment can also be implemented by means of a navigation system as it is provided according to a further variant of the inventive method. In this case, both the viewpoint and the perspective (as in conventional volume rendering) and the selection of the current volume data to be represented in real time are set by the navigation system. This enables a "fly through" through all volume data of an inherently closed, imaged subject. Previously known methods allow this only via selection in the data (MIP-only maximum values, but over the entire volume), via selection of a special path through hollow spaces connected

with pre-segmentation (actual fly-through) or via elaborate pre-calculations (segmentation, coloring, actually another data selection).

A further improvement of the representation of the imaged subject, most of all at the speed of the representation, is achieved according to embodiments of the inventive method when what it known as a "texture mapping" is additionally implemented (in particular according to the shear warp method), the volume elements of the first and/or second volume data set are interpolated, the first and/or second volume data set are filtered and/or the result of the filtering of the first volume data set and/or the result of the filtering of the second volume data set are buffered.

An exemplary embodiment is exemplarily shown in the accompanying schematic drawings. Thereby shown are:

| | |
|---|---|
| Figure 1 | a computer tomograph, |
| Figure 2 | a first volume data set with a virtual ray, acquired with the computer tomograph, |
| Figure 3 | a further volume data set produced from the volume data set shown in Figure 2, |
| Figure 4 | a graphical representation of a transfer function and |
| Figure 5 | a representation produced by means of the inventive method. |

Figure 1 schematically shows a computer tomograph with an x-ray source 1 from which a pyramidal x-ray beam 2 emanates whose edge rays are shown in a dash-dot manner in Figure 1, which x-ray beam 2 penetrates an examination subject (for

example a patient 3) and impinges on a radiation detector 4. In the case of the present exemplary embodiment, the x-ray source 1 and the radiation detector 4 are arranged opposite one another on an annular gantry 5. The gantry 5 is borne on a mounting device (not shown in Figure 1) such that it can rotate with regard to a system axis 6 which runs through the center point of the annular gantry 6 (compare arrow a).

In the case of the present exemplary embodiment, the patient 3 lies on a table 7 transparent to x-radiation, which table 7 is borne by means of a carrier device (likewise not shown in Figure 1) such that said table 7 can shift along the system axis 6 (compare arrow b).

The x-ray source 1 and the radiation detector 4 thus form a measurement system that is rotatable relative to the system axis 6 and can shift relative to the patient 3 along the system axis 6 such that the patient 3 can be irradiated from different projection angles and various positions with regard to the system axis 6. From the output signals of the radiation detector 4 thereby occurring, a data acquisition system 9 forms measurement values that are supplied to a computer 11 that (by means of methods known to the average man skilled in the art) calculates an image of the patient 3 that can in turn be reproduced on a monitor 12 connected with the computer 11. In the case of the present exemplary embodiment, the data acquisition system 9 is connected with the radiation detector 4 with an electrical line 8 that (in a manner not shown), for example, comprises a slip ring system or a wireless transmission path and with the computer 11 with an electrical line 10.

The computer tomograph shown in Figure 1 can be used both for sequence scanning and for spiral scanning.

In the sequence scanning a slice-by-slice scanning of the patient 3 ensues. The x-ray source 1 and the radiation detector 4 is [sic] thereby rotated around the patient

3 with regard to the system axis 6 and the measurement system comprising the x-ray source 1 and the radiation detector 4 acquires a plurality of projections in order to scan a two-dimensional slice of the patient 3. A slice image representing the scanned slice is reconstructed from the measurement values thereby acquired. The patient 3 is respectively moved along the system axis 6 between the scanning of successive slices. This event is repeated until all slices of interest are acquired.

During the spiral scan, the x-ray source 1 and the measurement system comprising radiation detector 4 moves [sic] continuously in the direction of the arrow b relative to the system axis 6 and the table 7, i.e. the measurement system comprising the x-ray source 1 and the radiation detector 4 move continuously on a spiral path c relative to the patient 3 until the region of interest of the patient 3 is completely acquired. A volume data set is thereby generated that, in the case of the present exemplary embodiment, is coded according to the DICOM standard typical in medical technology.

In the case of the present exemplary embodiment, a volume data set (comprised of a plurality of successive slice images) of the abdominal region of the patient 3 is created with the computer tomograph shown in Figure 1 with approximately 500 CT slices (slice images) of the matrix 512x512.

The volume data set is, for example, interpreted as slices parallel to the table 7 for the application in minimally-invasive surgery/laparoscopy. The slice orientation (coronary) is thereby approximately at a right angle to the viewing direction of a doctor (not shown in Figure 1) who normally views approximately perpendicular to the abdominal wall of the patient 3. In the case of the present exemplary embodiment, these slices are interpreted as textures or interpolated multi-textures and accounted for [sic] into a 3D representation according to the shear warp method (known characteristic of volume rendering). The volume data set 20 created from this is schematically shown in Figure 2. A virtual ray 21 emanating

in approximately the viewing direction of the doctor and running into the volume data set 20 is shown dashed in Figure 2. That coordinate axis of the original volume data set which, in the preferred observation direction of the operator, has the smallest angle relative to the ray 21 (thus runs closes to parallel to the ray 21 in the preferred direction) is designated as a main observation direction 22. The specified method functions relatively well with this one preferred direction for large data sets, as in this example, and also for deflections of the viewing direction up to approximately +- 80° to the sides or up/down. For an improved representation, one redirects to +- 45°, for example to slices that stand perpendicular to the first orientation (axial or sagittal). In principle, in the case of the preferred exemplary embodiment the 3D data are stored exclusively for the color lookup mode including black-and-white representation. On the one hand, for relatively large data sets this means a minimal storage requirement (for example 8-bit in 3D, for example 32-bit only for the display); on the other hand this means the possibility that the representation can be modified or, respectively, adapted via modification of the lookup table in real time.

A connection of the representation control with shading and depth information is now inventively provided via a lookup table. For this, in the case of the present exemplary embodiment a further volume data set 30 (shown in Figure 3) is produced in which the volume elements 23 of the volume data set are modulated per voxel with a depth value along the edge-parallel main observation direction as well as possibly with further filter responses and, coded via this one-time pre-processing, are stored in the working storage of the graphic card 13 of the computer 11.

In the case of the present exemplary embodiment, the modulation of the individual volume elements 23 of the volume data set 20 occurs along the main observation direction 22, and in fact such that the grey values (for example Hounsfield units in CT) of the volume elements 23 of the volume data set 20, which are further

removed from the viewpoint of an observer along main observation direction 2, are accounted for with a smaller factor than the grey values of the volume elements 23 that are located closer to the observer.

The further volume data set 30 is subsequently accounted for in real time in the representation with an alpha value possibly modified relative to the other volume rendering and shown under cooperation with a lookup table (transfer function).

In the case of the present exemplary embodiment, the transfer function has the form of a canted bar 40, as this is schematically shown in Figure 4. The coding in the volume data set 30 and the application of the transfer function ensues [sic] such that the displacement range of the canted bar 40 corresponds to the depth of the volume data set 30, and therewith the entire color or, respectively, grey value range (in 8-bit, for example 256 elements in size) of the volume elements of the data set 30 can be imaged. The depth of the further volume data set 30 is shown with an axis 31.

In the real-time generation of the 3D view, each of the coded slices (textures) of the further volume data set 30 is distorted as it corresponds to the current perspective view with central ray 21 and then ultimately added into an accumulator texture after multiplication with the cited blending alpha. In the case of the present exemplary embodiment, a real-time interpolation is also used in the graphic card 13.

The accumulator storage (for example a display buffer) in the graphic card 13 contains a shaded, if applicable edge-emphasized 3D image with the same coding and accounting, in which are shown one or more depth ranges of the original volume data set 20 shown in Figure 2. The sensing of the desired depth ensues via the corresponding setting of the lookup table. A refined, also non-linear coding can be effected in order to, for example, more clearly separate or fade out

uninteresting structures such as, for example, (in most cases) bones (ribs). Such a special coding should be oriented to the conditions of the scale of the measurement values, in the case of the present exemplary embodiment the Hounsfield units of the individual volume elements of the volume data set 20.

For example, the values of the lookup table (transfer function) appear so: the canted rectangle extends into the depth range of approximately 136 mm to 120 mm, corresponding to positions 136 through 120 for the lookup function. Given pure grey-value coding, the display color value "255, 255, 255" stands in position 136, decreasing, for example, to the value "50, 50, 50" at position 120. This is amplified by the depth coding in the volume data set 30, in that, for example, in a lateral plan view of a subject surface, surface volume elements lying further to the rear are rendered transparently darker in the alpha integration than volumes elements lying further towards the front, and the plastic or, respectively, the amplified spatial effect results from this.

The overall accountings are, for example, activated by a shift control or a mouse movement or ensue continuously via updates of the position and orientation coordinates of a navigation system (not shown in detail in Figure 1 but generally known to the average man skilled in the art), such that approximately 15 renderings per second are achieved, for example with standard graphic cards obtainable at present.

A representation produced with the inventive method is exemplarily shown in Figure 5 in the form of an image 50.

In the case of the present exemplary embodiment, the volume data set 20 is produced with a computer tomograph and exists in the form of a plurality of successive computer-tomographic slice images. The volume data set 20 can, however, also be produced with other imaging apparatuses such as, in particular, a

magnetic resonance apparatus, an x-ray apparatus, a ultrasound apparatus or a PET scanner. The volume data set 20 also does not have to exist in the form of a plurality of successive computer-tomographic slice images.

The inventive method can also be used for imaged technical subjects.

The exemplary embodiment likewise has only exemplary character.